us to exclude the possibility of fission of protactinium by thermal neutrons; but the yield of such a process should at any rate be very much smaller than in uranium. An accurate determination of the threshold of neutron energy for protactinium fission would of course be very important and might perhaps be most easily obtained by a comparison between the fission yields for fast neutrons of well-defined energy in protactinium, uranium, and thorium, like that provided for the two latter elements by the experiments of Ladenburg, Kanner, Barschall and Van Voorhis,[3] as discussed in Section IV, C (see especially Fig. 6) of our paper.

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On Pair Emission in the Proton Bombardment of Fluorine

The gamma-rays emitted when fluorine is bombarded by protons have been studied by Fowler and Lauritsen, who have shown that these gamma-rays are monochromatic, with an energy of (6.3±0.1) Mev, independent of the proton energy; that they are emitted by an excited oxygen nucleus formed from the compound nucleus Ne^{20} by short range alpha-particle emission; and that they are emitted strongly only at certain well-defined proton energies which correspond to resonance levels in Ne^{20}. To account for the sharpness of these resonances it has been suggested that the parity-angular momentum selection rule prohibits the emission from these states of a long range alpha-particle, with the formation of a normal oxygen nucleus.

Recently Fowler and Lauritsen[1] have shown that under proton bombardment fluorine also emits electron pairs of total energy (5.9±0.5) Mev. The excitation function for the pairs also exhibits resonances, but uncorrelated with those for the gamma-rays—at some energies there are more than 100 times as many gamma-rays as pairs; at others the number of gamma-rays is comparable with, and may be smaller than, the number of pairs. Since, for any multipole order the pair creation internal conversion coefficient for 6-Mev gamma-rays is less than half of one percent, the pair emission must arise from a nuclear transition for which gamma-radiation is strictly forbidden, i.e., either Ne^{20} or O^{16} possesses an excited state with $j=0$ with no lower states of nonvanishing j, from which these pairs must originate. Since Ne^{20} is known from the work of Bonner to have a number of low-lying excited states, we are led to ascribe the pairs to a transition from an excited state of oxygen, with $j=0$ and about 6 Mev excitation energy, to the ground state.

If long range alpha-particle emission from the corresponding Ne^{20} is to be forbidden by the parity-angular momentum selection rule, this state in oxygen must be of odd parity (0^-). A ($0^-\rightarrow 0^+$) transition, however, corresponds to vanishing matrix elements of charge and current density; decay by pair emission can only occur if there is a nonelectromagnetic coupling between nuclear particles and the pair field. Thus, a coupling term of the form suggested by the Gamow-Teller, theory of nuclear forces,

$$(\boldsymbol{\sigma}_{\mathrm{el}}\cdot\boldsymbol{\sigma}_{\mathrm{prot}}) \quad \text{or} \quad (\boldsymbol{\sigma}_{\mathrm{el}}\cdot\boldsymbol{\sigma}_{\mathrm{neut}}),$$

would permit this transition to occur with the emission of pairs. A value of the coupling constant much smaller than that suggested by these authors would be sufficient to give a rate of pair emission greater than the rate of the competitive process of two-quantum emission. This latter process takes place by the successive emission of an electric dipole and a magnetic dipole quantum, through the intermediary of states possessing the character 1^+ or 1^-. The lifetime of the 0^- state associated with this method of decay may be roughly estimated at 10^{-6} sec.

The only alternative to this radical suggestion is to assume the excited state in oxygen to be of even parity (0^+). Pair emission, no longer forbidden, proceeds at the rate:

$$\left(\frac{1}{135\pi}\right)\left(\frac{e^2}{\hbar c}\right)^2\left(\frac{\gamma^5}{\hbar^5c^4}\right)|(\psi_{\mathrm{exc}},\ \textstyle\sum_\iota r_\iota^2\psi_{\mathrm{norm}})|^2,$$

which exceeds the rate of two-quantum emission:

$$\left(\frac{2}{7}\right)\left(\frac{\gamma}{\Delta}\right)^2\left(\frac{1}{135\pi}\right)\left(\frac{e^2}{\hbar c}\right)^2\left(\frac{\gamma^5}{\hbar^5c^4}\right)|(\psi_{\mathrm{exc}},\ [\textstyle\sum_\iota \mathbf{r}_\iota]^2\psi_{\mathrm{norm}})|^2$$

since γ, the energy emitted in the transition, is rather less than Δ (~20 Mev), the mean energy difference between the ground state and the excited states of type 1^- which act as intermediates in the double electric dipole emission process. (The summation in these formulae is to be extended over all nuclear protons.) The quanta would give a weak continuous spectrum extending up to 6 Mev and would not have been observed.

This second alternative involves abandoning the explanation of the long life of the resonance states of Ne^{20} in terms of the parity-angular momentum selection rule. Neither spin nor isotopic spin conservation can appreciably reduce the probability of long range alpha-particle emission. Indeed, if the first excited state of O^{16} is 0^+, it would seem likely on the basis of the alpha-particle model, which could make this intelligible, that this state has the same spin and isotopic spin as the ground state. For this reason we must expect the yield of long range alpha-particles to show resonance at the energies which produce pairs. Some indication that this may be so is afforded by the fact that the maximum pair yield found by Fowler and Lauritsen is under a tenth of the maximum gamma-ray yield, which suggests that the emission of long range alpha-particles competes with the alpha-particle emission leading to the excited state. We should in fact expect that at bombarding energies of the order of 1 Mev, where pair emission becomes appreciable, the Coulomb barrier would not materially reduce the emission probability of even the short range alpha-particles. The value of 10 to 1 suggested by the observed yield of pairs for the ratio of the decay rates of

long and short range alpha-particles is thus a reasonable one. The fact that the gamma-ray yields are larger, and, near the 330-kev resonance, much larger than the yield of long range alpha-particles, makes it necessary to assume that, at least for this γ-ray resonance, the long range alpha-emission is either forbidden or reduced.

If then the excited state is even, we should expect the resonance yield of long range alpha-particles to be comparable with, and probably considerably greater than the yield of pairs. If this is not so, the pair emission itself would seem to provide strong evidence for a nonelectromagnetic coupling between electrons and heavy particles.

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Observation of the Spectrum of Ne V

Previous investigations of the spectra of rare gases[1] have been limited in the extent of ionization which was produced in the gas atom. The development of methods of study of atoms which can be fixed in an electrode in solid form has extended the spectra of such ions to far greater stages of ionization. In an attempt to close some of the gaps in isoelectronic sequence data, experiments have been undertaken to determine whether higher stages of ionization can be studied in the rare gases. This communication is a preliminary report of some observations of the spectra of neon.

A periodic disruptive discharge in neon gas enclosed in Pyrex and quartz capillaries of about 2 mm bore and 15 mm length has been used as a source of light on a 3-meter grazing incidence vacuum spectrograph. On the resulting spectrograms the principal lines of Ne III, Ne IV, and Ne V have been identified.

The wave-lengths of the lines attributed to Ne V are given in Table I. The identification seems certain inasmuch as the lines are well isolated on the plates and their positions can be predicted with good accuracy from isoelectronic sequence data. The wave-lengths given must be regarded as tentative as they may be in error by as much as 0.05A because of the scarcity of standard lines on the plate from which the measurements were taken.

It is expected that refinements of experimental technique will permit fuller development of the spectrum of Ne V and more accurate wave-length measurements. Since the lines due to Ne V are equally as strong as those due to Ne III and Ne IV on the present plates, it is possible that this method will provide for the excitation of still higher stages of ionization. Experiments are being carried out with argon, krypton and xenon.

TABLE I. *Spectrum lines attributed to* Ne V.

λ VAC.	ν CM^{-1}	TRANSITION
572.38	174,708	$2p^2\,{}^3P_2-2s2p^3\,{}^3D_{2,1}{}^0$
572.12	174,787	$2p^2\,{}^3P_2-2s2p^3\,{}^3D_3{}^0$
569.84	175,487	$2p^2\,{}^3P_1-2s2p^3\,{}^3D_{2,1}{}^0$
568.45	175,918	$2p^2\,{}^3P_0-2s2p^3\,{}^3D_1{}^0$
483.00	207,039	$2p^2\,{}^3P_2-2s2p^3\,{}^3P_2{}^0$
481.30	207,770	$2p^2\,{}^3P_1-2s2p^3\,{}^3P_{1,0}{}^0$
480.38	208,168	$2p^2\,{}^3P_0-2s2p^3\,{}^3P_1{}^0$

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Work Functions of Different Faces of Silver Single Crystals

The work functions of the (100) and (111) faces of silver single crystals have been determined by a photoelectric method after extended outgassing of the crystals in a high vacuum. The crystal faces were prepared by a method described previously.[1] The equilibrium value of the work function for the (100) face is 4.81 ± 0.01 electron volts. This value was obtained after 2283 hours of heating at various temperatures up to visible red heat. 356 hours of additional heating did not change this value. After the crystal had subsequently remained at room temperature for 2130 hours, at a pressure of 1 to 3×10^{-8} mm Hg, the work function decreased to 4.65 ev. After 100 hours of additional heating of the crystal the work function increased to 4.79 ev, and after an additional 118 hours of heating it returned to the equilibrium value of 4.81 ev.

The equilibrium value of 4.75 ± 0.01 ev for the (111) face was obtained after 1227 hours of heating at temperatures similar to those above. This crystal had been outgassed in two previous experiments so that a much shorter time was required to reach the equilibrium value of the work function than for the (100) face. The above equilibrium value was not changed by 407 hours of additional heating. At this time the crystal became slightly contaminated while heating a tantalum plate near it. The effect of the contamination was to cause a failure of the experimental results to fit the Fowler theoretical curve.

Measurements of the contact potential difference, by the Kelvin null method, between the two crystal faces at frequent intervals during outgassing agreed with the differences of the photoelectric work functions to within ±0.01 volt until the results for the (111) face failed to fit the Fowler theoretical curve.

We believe that these values are the best that can be obtained by heating since silver crystals etch rapidly, thus exposing other faces, when heated at temperatures where appreciable evaporation occurs.[2] The above values may be compared with 4.74 ev, previously obtained by Winch,[3] for polycrystalline silver after heating for 1200 hours which included short intervals at temperatures as high as 850°C where evaporation is rapid.

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